

[54] **FUNCTION CONTROL CIRCUIT FOR EDM POWER SUPPLY**

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[51] Int. Cl.:..... **B23k 9/16**

[58] Field of Search..... **219/69 C, 69 S, 502, 69 P, 219/69 G; 323/21**

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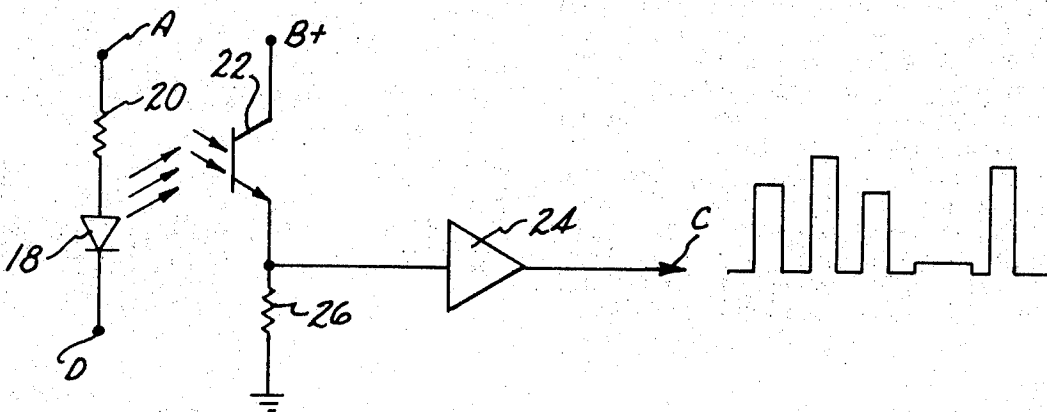
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[57]

ABSTRACT

A system for controlling an electrical discharge machining apparatus wherein the system is rendered responsive to an electrical gap parameter such as gap current or gap voltage level. Included in the system for responding to gap condition is a sensing circuit which includes a light-emissive device connected in circuit with the gap or with other essential operating elements such that there is provided a light output of an intensity proportional to gap current or voltage. A second, light responsive device such as a phototransistor or photo diode is used to convert the light signal into an electrical control signal, which signal in turn is utilized in a function control for the electrical discharge apparatus. The function control exercised includes machining power pulse on-time and off-time control, interruption of machining power responsive to gap short circuit condition, servo feed by providing relative movement of controllable speed and direction between a tool electrode and the workpiece, the gap width, and interruption of the power for the power supply in order to protect against gap short circuit condition arising from failure of an essential switching element in the EDM power supply such as one of the output electronic switches.

15 Claims, 9 Drawing Figures



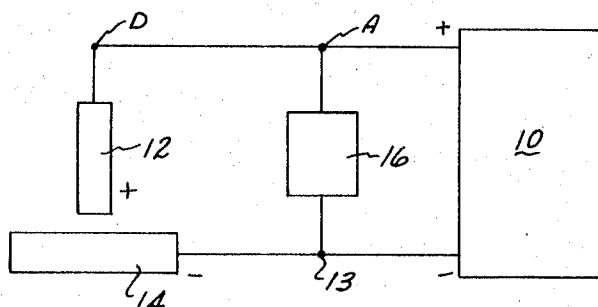


Fig-1

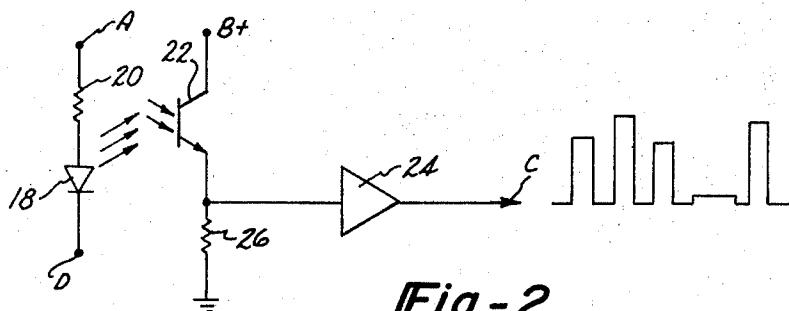


Fig-2

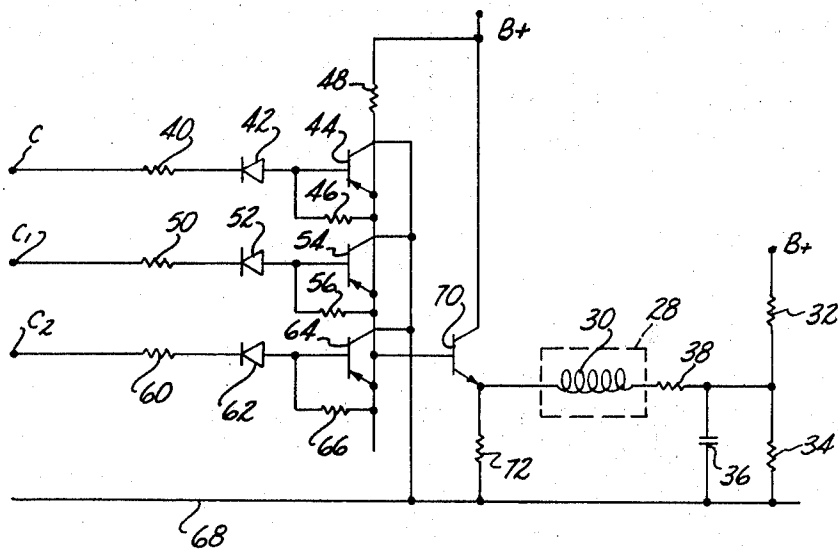


Fig-3

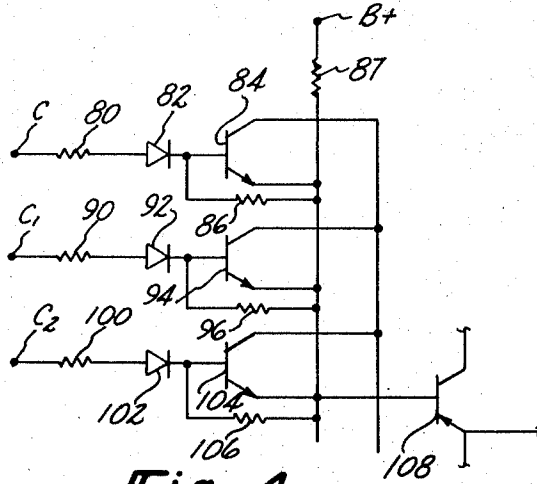


Fig-4

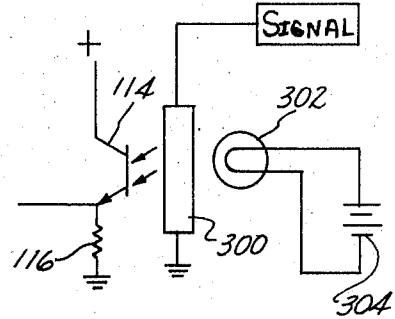


Fig-8

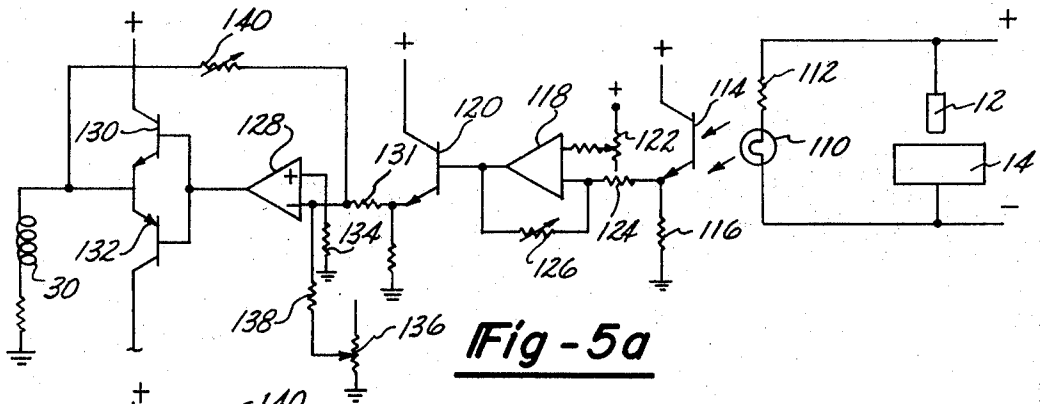


Fig-5a

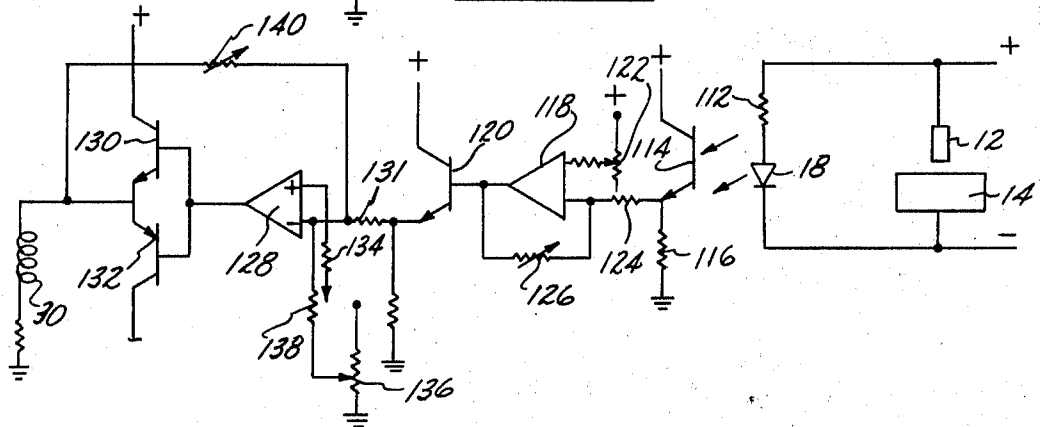


Fig-5b

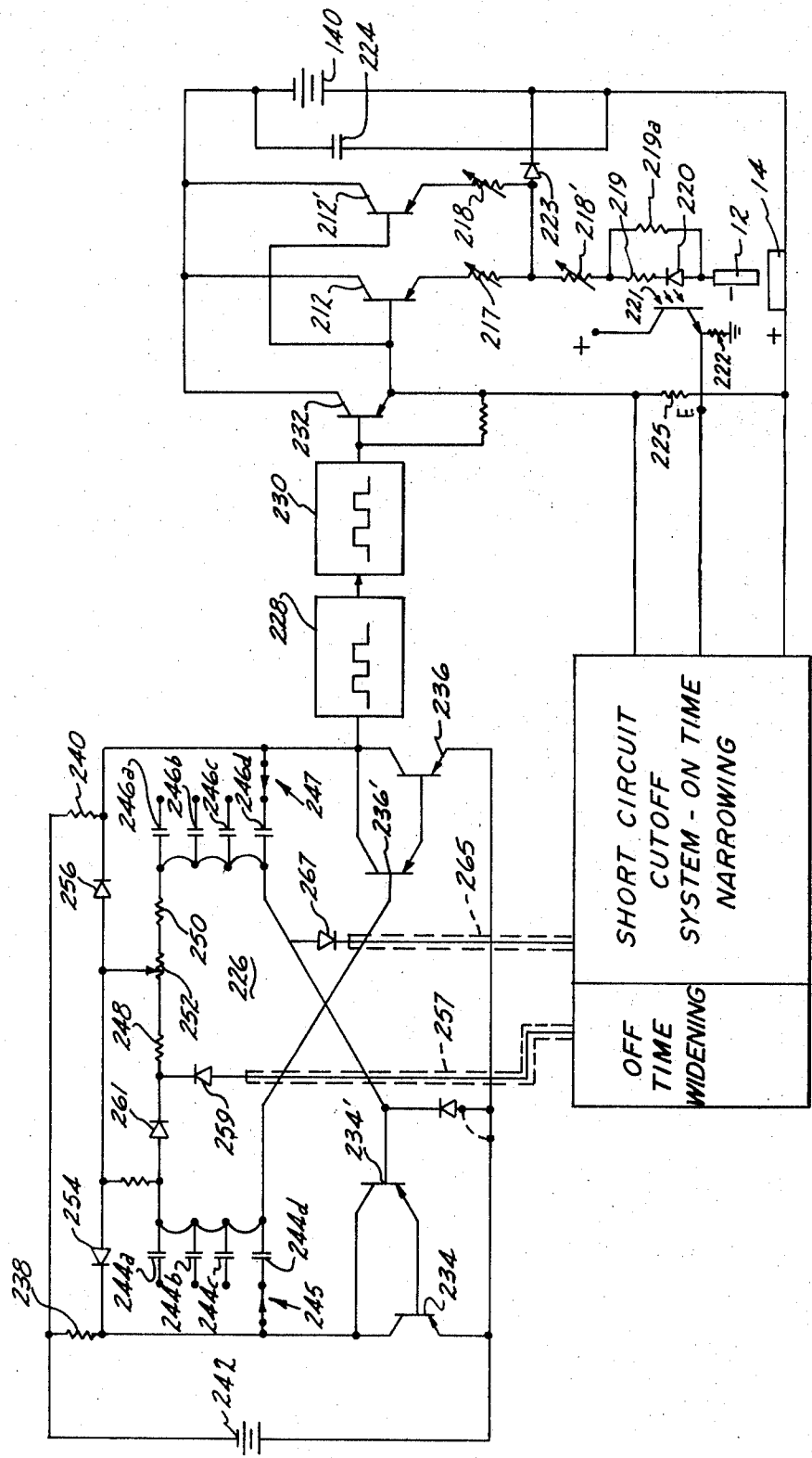


Fig - 6

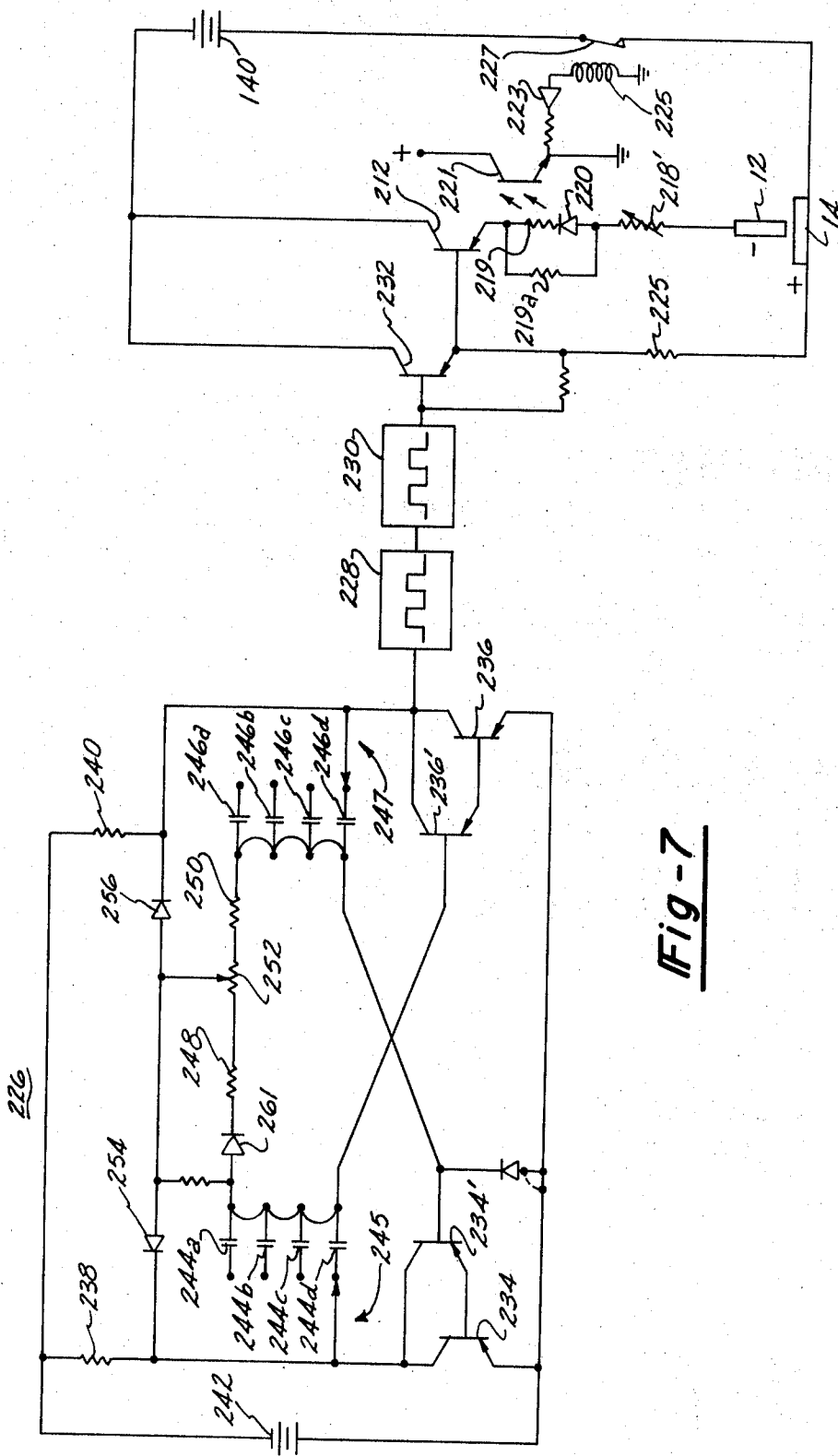


Fig - 7

FUNCTION CONTROL CIRCUIT FOR EDM POWER SUPPLY

REFERENCE TO RELATED APPLICATIONS

Reference is made to my U.S. Pat. No. 3,705,969, issued Dec. 12, 1972, for "Cut-Off Protection System for EDM Power Supply" and to U.S. Pat. No. 3,697,719 issued Oct. 10, 1972, for "Pulse Narrowing and Cut-Off Protection System for Electrical Discharge Machining", both of which applications are of common ownership herewith. The present invention represents an improvement with respect to the pulse narrowing control circuit illustrated therein particularly with respect to the type of gap voltage sensing network used and the resultant protection system provided.

Reference is also made to my U.S. Pat. No. 3,727,024, issued Apr. 10, 1973, for "Electrical Discharge Machining Servo Control System", which application is of common ownership herewith. The present application includes as one species of the invention an improved gap voltage sensing network for controlling servo feed with reference to gap voltage level.

Reference is further made to my U.S. Patent application Ser. No. 219,022 filed on Jan. 19, 1972 for "Short-Circuit Protection System for EDM Power Supply Apparatus". The present invention includes one species which relates to a short circuit protection system in which the presently disclosed sensing circuit provides an alternate method to that disclosed.

BACKGROUND OF THE INVENTION

The electrical discharge machining art has advanced from the early stages in which relaxation oscillators were used to provide machining power pulses to the gap for eroding portions of an electrically conductive workpiece in the pattern of a tool electrode. Independently timed and controlled pulse generators are now almost universally used and in these generators the electronic switches employed are now generally in the form of solid state switches particularly transistors. In the electrical discharge machining process, it is necessary as the workpiece material is removed that a predetermined gap be maintained between the tool electrodes and the workpiece through an automatic servo feed system which provides a continuous advance into and toward the workpiece as material removal progresses. During the electrical discharge machining process, a fluid coolant, generally a liquid, is circulated through the machining gap to flush the workpiece particles from the gap. The coolant is usually furnished under pressure by a pump through one or more holes provided in the electrode. One necessary and defining characteristic of electrical discharge machining is that the coolant is a dielectric fluid such as kerosene, transformer oil, distilled water or the like. The dielectric fluid is broken down in minute, localized areas by the action of the machining power pulses passed between the closely opposed surfaces of the tool electrode and workpiece. For control of the servo feed system, there is generally utilized an electrical signal from the machining gap in order to control the rate and the direction of servo feed. In many cases this gap signal is compared to an adjustable reference voltage so that the operator can select the rate of servo feed desired for the particular operating condition.

It will thus be seen that with respect to the servo feed of the gap elements in electrical discharge machining a parameter of the gap, whether it be average gap voltage as shown and described in Williams U.S. Pat. No. 2,841,686 issued July 1, 1958, peak gap voltage as shown and described in Webb Pat. No. Re. 25,542 issued Mar. 24, 1964, or as in any other EDM servo feed systems, there is required a reliable signal from the gap. The problem has been complicated by the fact that for certain electrode materials, such as graphite, the normal EDM gap polarity in which the tool electrode is negative and the workpiece positive must be reversed to provide for best machining results. Additional problems are encountered when the same power supply is used to feed several different machining gaps, that is where several electrodes are used to simultaneously cut several holes in the same workpiece, or, alternately, several electrodes are used to cut holes at the same time in different workpieces. As power supplies have come to have more power capability, lead lengths in order to handle the multiple gap systems have become longer and it has become continuously more difficult to provide for gap sensing and for those circuit connections which will be immune to noise in the electrical system and provide reliable voltage signals to control servo feed.

Other function control circuits are likewise dependent in their operation upon the magnitude of electrical signals derived from the machining gap, which signals again operate as an index to control, for example, interruption of power when a gap short circuit condition has occurred. The gap short circuit condition most often occurs due to a build-up of the eroded materials from both the electrode tool and workpiece across the machining gap. Unless this condition is rapidly alleviated, either by electrode back-up or by instantaneous interruption of power to the gap, serious damage can result to either or both the tool electrode and the workpiece. This problem has been solved by the prior art by the development of a number of gap short circuit protection systems such as that disclosed and claimed in Senowitz U.S. Pat. No. 3,439,145 issued on Apr. 15, 1969 for "EDM Power Supply Circuit". The need of a reliable sensing system responsive to gap voltage to control such a protection system is met by the system according to the present invention.

An additional problem arises from the failure of one or more of the electronic output switches, generally with their power conducting electrodes in a shorted condition. Power to the gap must be interrupted until the defective transistor can be located and replaced. The problem again is one of providing a reliable sensing circuit capable of responding to such a condition and providing an output signal to provide the necessary protection function control.

In some gap short circuit protection systems there is provided not a total interruption of the machining power but rather a control of the individual machining power pulses themselves such as by narrowing their on-time or increasing the off-time, or in some cases performing both these functions together. An example of an on-off time control system for controlling pulse width is disclosed in my aforementioned U.S. Patent application Ser. No. 196,439, a portion of which application has been incorporated by reference into this application as an exemplary embodiment of the invention.

By way of summary, it will be seen that the prior art protection systems for electrical discharge machining apparatus have the common problem of providing a control signal whether it be from the machining gap itself or from an intermediate part of the power supply such as the electronic output switch, which signal represents an abnormal or malfunctioning condition and actuates a protection circuit to suitably respond either by way of interrupting the power to the gap, reducing the power to the gap, or initiating a servo feed back-up operation to protect the gap elements from possible damage.

It will be understood in the specification that when I refer to "electronic switch" I mean any electronic control device having three or more electrodes comprising at least two principal or power conducting electrodes acting to control current flow in the power circuit, the conductivity between the principal electrodes being controlled by a control electrode within the switch whereby the conductivity of the power circuit is controlled statically or electrically without movement of mechanical elements within the switch. Included within the definition are transistors in which turn-on is accomplished by a control voltage applied to the transistor control electrode and in which turn-off is accomplished automatically in response to removal of that control voltage. Also included in the definition are devices of the gate type in which turn-on is accomplished by a control voltage applied to the control electrode, which control voltage may be then removed and in which turn-off is accomplished by application of a subsequent control voltage to the control electrode. An additional class of electronic switches, called "electronic trigger devices", falls within this definition and includes ignitrons, thyratrons, semi-conductor controlled rectifiers and the like. By electronic trigger device I mean any electronic switch of the type which is triggered on at its control electrode by a pulse and is turned off by reverse voltage applied for a sufficient time across its principal electrodes.

SUMMARY OF THE INVENTION

Viewed in its broadest sense in light of the prior art just discussed, the present invention provides an improved sensing network particularly adaptable for use in an electrical discharge machining power supply in which the signal is both generated and transmitted to provide a protection function or a cut-off function of the power supply. The invention includes the use of light-emitting devices, such as light-emissive diodes, which provide an output signal responsive to the magnitude of current passing through the device. The signal which is then used to operate a light responsive device such as a phototransistor or a photo diode which in turn has a conductivity controllable according to the energy level of the light given off by the light-emitting device. The signal may be generated by light-emitting diodes, such as for example gallium phosphide diodes, or alternately in a different version of the present invention as will be illustrated, it is possible to use incandescent light bulb type devices connected with the gap to provide a light signal variable according to current being conducted through the device and then available in turn to control the generation of an electrical control signal through an associated phototransistor. The advantages of such a system include the feature that no electrical connection directly between the light-

emissive device and the photosensitive device is required. The relative polarities of the two devices make no difference in their operation. Also, the polarities with respect to the bulb type light-emissive device and the gap and the direction in which current is passed are of no importance so that with certain embodiments of the present invention it is possible to have changeover between either gap polarity and still maintain a fully operative gap condition sensing network. The light-emissive diodes have a response time which is fast enough to respond to high frequency machining power pulses being passed across the gap. In accordance with the servo feed embodiments of the present invention, a large number of gaps can be handled at the same time for split or multiple lead machining operation. The present invention provides a substantially improved system for sensing gap condition which eliminates the requirement for high gain amplifiers and comparative level sensors, all of which have a common ground reference.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings in which like reference numerals have been used to designate like parts herein referred to throughout the several views:

FIG. 1 is a block diagrammatic drawing illustrating the present invention as it is embodied in an electrical discharge machining power supply with relationship to the machining gap;

FIG. 2 is a schematic partly in block diagrammatic form showing one embodiment of the present invention using a light-emitting diode;

FIG. 3 is a schematic drawing showing a multiple lead servo feed system for controlling the feed simultaneously of a plurality of tool electrodes;

FIG. 4 is a servo feed circuit substantially similar to that shown in connection with FIG. 3 but incorporating a different polarity type transistor switch;

FIG. 5A is a schematic showing of one embodiment of the present invention for use in conjunction with a servo feed system;

FIG. 5B is a schematic showing an alternate embodiment of the present invention for use in conjunction with a servo feed system;

FIG. 6 is a simplified schematic illustration of an EDM power supply in which the present invention is utilized to control a short circuit protection system to adjust machining power pulse on-off time duration;

FIG. 7 is a schematic representation of an EDM power supply showing a voltage sensing network according to the present invention used to control power interruption responsive to failure of one of the output electronic switches or transistors; and

FIG. 8 is a schematic showing a liquid crystal embodiment of a light emitting device.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a drawing showing an electrical discharge machining power supply 10 having its output connected across a machining gap between a tool electrode 12 and a workpiece 14. A more detailed showing of the basic operating parts of an EDM power supply will be shown in FIG. 6 hereinafter. A light-emitting device 16, sometimes hereinafter referred to as an LED, may be embodied as light-emitting diodes or bidirectional light emission devices such as incandescent light bulbs. In any case, the light-emitting device used may

be described as any device having a light energy output which is proportional to the input current density. Ordinarily, the light-emitting device is then used in the manner shown in FIG. 2 to control the conductivity of a light responsive switching means such as a phototransistor to provide an electrical control output signal. It will be understood that in FIG. 1 the light-emitting device 16 is connected across the gap between terminals A and B, but alternately it may be connected in series with the gap between terminals A and D as shown.

FIG. 2 shows a light-emitting device embodied as a light-emitting diode 18 which may be connected in series with the machining gap, for example, in series with the tool electrode 12. A suitable current limiting resistor 20 is connected in series with the light-emitting diode 18. As indicated in the drawing, the light energy emitted by diode 18 is communicated to the base or control electrode of a phototransistor 22, which in turn provides an electrical control output signal through an intermediate amplifier stage 24 and thence to one or more of the function control circuits as will be further illustrated hereinafter. The phototransistor 22 has its collector coupled to a suitable B+ source and a load resistor 26 is connected in series with emitter of the phototransistor 22. It will be seen that the electrical output signals have a variable amplitude which may fluctuate as shown at the right-hand side of FIG. 2.

The FIG. 3 schematic shows a servo feed control system particularly useful in connection with multiple gap machining operation in which a plurality of outputs are passed through terminals in the manner indicated to control the servo feed motor, thus maintaining the proper gap spacing between the electrodes 12 and workpiece 14. The basic control circuit may be connected, for example, to one terminal of a control coil 30 for a servo valve control coil indicated by the numeral 28. The circuit of FIG. 3 is adapted for use with a system in which the electrode carrying ram is operated with an electro-hydraulic motor for the motive means. It will be seen that the circuit of FIG. 3 includes a plurality of input means. As has already been indicated, an incandescent light bulb may be substituted for the light-emitting diode 18, with the advantage that the polarity of the gap or its reversal has no effect on the light bulb operation as it relates to sensing current flow through the bulb. In the FIG. 3 circuit, the servo valve coil 30 has connected at its right end a reference voltage. The resistors 32, 34 with filter capacitor 36 and a series resistor 38 serve to provide a reference voltage against which the control input signals from a plurality of gaps are used to provide a single control signal. In the FIG. 3 circuit, LED's are connected in series with each of three different gaps. The output signal from the first of such phototransistors 22 is provided through a series resistor 40 and diode 42 to the base of an associated PNP transistor 44. The PNP transistor 44 has a resistor 46 coupled across its base end emitter, while a source of B+ voltage is connected through a series current limiting resistor 48 to the emitter of the transistor 44. The circuit just referred to is duplicated in each of the other two networks and with identifying numerals being applied to each corresponding element as follows: In association with the C₁ terminal, a series resistor 50, a signal diode 52, a transistor 54 and a resistor 56 are included. In the final lowermost branch associated with the C₂ terminal, there are included a series resistor 60, a diode 62, a transistor 64 and a resistor 66.

It will be seen that the three transistors 44, 54 and 64 all have their collectors connected to a minus gap lead 68. The emitters of each of the aforesaid transistors are all connected to the base of a single control transistor 70 of the NPN type. The transistor 70 has its collector connected to the B+ voltage source and a load resistor 72 is connected in series with its emitter. The emitter of the transistor 70 is also coupled to the left-hand terminal of the servo control coil 30. It will be seen that when the gap voltage level at any one of the three gaps being monitored drops to a sufficient level, there will be provided an increased output signal from its corresponding terminal C, C₁ or C₂. This will cause a correspondingly increased current flow from the transistor 70 to provide back-up through operation of the servo coil 20 and the electro-hydraulic motor to which it is connected. It will be understood that the control signal provided to the servo valve coil 30 is related to the excursions occurring in gap voltage.

The circuit of FIG. 4 is quite similar to the circuit of FIG. 3 except that the input signals from the several sensing networks at terminals C, C₁ and C₂ are of the opposite polarity so that the included diodes are shown in their reversed connection and the plurality of transistors incorporated in the control circuit are NPN transistors rather than PNP transistors. The control transistor 70 has been changed to a transistor of the PNP type. The circuit included in the C lead includes a series resistor 80, a diode 82, a NPN transistor 84 and a shunt resistor 86. A suitable magnitude B+ source is connected to the upper terminal of a resistor 87. In the C₁ lead, there are connected a resistor 90, a diode 92 having its cathode connected to the base of an NPN transistor 94, and a resistor 96 connected across the base emitter junction. In the C₂ network, there are included a series resistor 100, a diode 102 having its cathode connected to the base of an NPN transistor 104, and a resistor 106 connected across the base emitter junction of the transistor 104. The transistors 84, 94 and 104 are all connected in common emitter configuration and provide a control signal to the base of the control PNP transistor 108. The balance of the circuit, including the servo valve coil and reference voltage, are the same as that shown in FIG. 3 and have been omitted in the interest of simplification. It will be seen that whenever the gap voltage drops to a level approaching gap short circuit, the LED associated with that gap will experience a change in its output of light energy, which change is communicated to the associated phototransistor or photo diode to provide a control electrical signal through the several networks to terminals C, C₁ and C₂ to thus control the current flow through the servo coil 30 to provide back-up of the ram. It will be understood that in the case of multiple electrode operation, the several electrodes are generally insulated one from the other and mounted on a common ram. When a gap short circuit is experienced with respect to one of the electrodes, all of them are then backed up to alleviate the short circuit condition. The response time of the LEDs is sufficiently rapid to respond to pulse by pulse changes in the machining power pulses being passed across the gap, and accordingly the response time of the servo system is sufficiently rapid to remove the electrodes from the workpiece before serious damage can occur. The circuit of FIG. 4 has additional advantages that may be used with sensing networks other than those incorporating LEDs. For example, the input

at terminals C, C₁ and C₂ may be derived from simple diode-capacitor sensing networks, in which case the input would be indicative of peak gap voltage level or, alternately, from a resistor-capacitor network, in which case the input would be representative of average gap voltage.

FIG. 5A shows a servo control system in which the LED is embodied as an incandescent light bulb 110 connected in series combination with a resistor 112, with the combination coupled across the machining gap between the electrode 12 and the workpiece 14. The light energy output from the bulb 110 is transmitted to the base of a phototransistor 114 to control its conductivity. The phototransistor 114 has a load resistor 116 connected in series with its emitter and an intermediate amplifier stage 118 is coupled between the emitter of the phototransistor 114 and a second transistor 120. Associated with the amplifier 118 are a null adjust potentiometer 122, a series signal resistor 124 and a variable resistor 126 for gain adjustment. A second amplifier stage 128 is connected to the output from the transistor 120. The signal from the emitter of the transistor 120 is passed through a signal resistor 131 and amplified to provide a control signal for a following push-pull stage incorporating a pair of transistors 130 and 132. The amplifier stage 128 has a resistor 134 connected with its plus terminal 134. The minus input terminal is connected to a selectively adjustable servo reference voltage provided by a potentiometer 136. A fixed magnitude series resistor 138 is connected between the slider of the potentiometer 136 and the minus input terminal of the amplifier 128. It will be seen that the transistors 130 and 132 are of NPN and PNP configuration, respectively, so that one or the other is rendered conductive according to the signal received at its base. The direction and magnitude of current flow through the servo control valve coil 30 is thus suitably regulated to provide an upfeed or downfeed of the electrode 12 in accordance with the level of gap voltage being sensed by LED bulb 110, and subsequently converted to an amplified electrical control signal by the circuit. A suitable gain adjust rheostat 140 is connected in the circuit as shown.

The circuit of FIG. 5B is essentially the same as that of FIG. 5A except for the inclusion of a light-emitting diode 18 in place of the light bulb 110 of FIG. 5A. In like manner to the circuit of FIG. 5A, there are included several intermediate amplification stages between the phototransistor 114 and the push-pull stage of transistors 130 and 132 so that the conduction of one or the other will control the direction of current flow through the servo control coil 30 and hence control the upfeed or downfeed of the electrode in accordance with the changes occurring in gap voltage. The basic operating principle of the two circuits are based upon the fact that the impinging light energy is capable of releasing current carriers in the semi-conductor material of the phototransistor 114. Otherwise stated, the light energy provided by the LED, whether it be the diode 18 or the light bulb 110, will free current carriers, thereby reducing the resistance of the material.

FIG. 6 is a combined schematic and block diagrammatic drawing of an electrical discharge machining power supply in which the main DC machining power source 140 is shown connected in series with the power conducting or principal electrodes of a pair of parallel connected output transistors 212 and 212' and in series

with the machining gap which includes the electrode 12 and the workpiece 14. It will be seen that the polarity of the gap is different from that previously illustrated in the other Figures of this application and the electrode is of the negative polarity as normally used with metallic type electrodes. The gap current level is selectively controlled by the magnitude of series resistors 217, 218 and 218'. A light-emitting diode 220 is between the electrode 12 and the output stage transistors 212 and 212' to provide a light output signal for the control of the electrical signal outputs of the associated phototransistor 221. The diode 220 is connected in series combination with a resistor 219 and the combination is connected across a resistor 219a. A resistor 222 is coupled to the emitter of the phototransistor 221. A terminal E serves as the gap voltage input terminal to a system for controlling short circuit on-time narrowing and off-time widening. Reference is made to my aforesaid U.S. application Ser. No. 196,439 for a full description of the circuit, its component and the mode of operation of the short circuit cut-off system indicated in block form in FIG. 6. The importance of that circuit in conjunction with the present invention is a new and improved system for sensing an electrical parameter of the gap and providing an electrical output signal for function control of the EDM power supply. A diode 223 is used to connect the transistors 212 and 212' to the positive terminal of the DC source 140 to eliminate damaging high voltage spikes. A capacitor 224' provides decoupling to eliminate voltage drops due to lead inductance from the power source 140. A multivibrator stage 226 and several intermediate driver stages 228, 230 and 232 are used to turn the output stage transistors 212 and 212' on and off with precisely controllable frequency and pulse duty factor. The resistor 225 forms a DC ground for the driver transistor 232. In the interest of simplification and brevity, the driver stages 228 and 230 have been illustrated in block diagram form.

The multivibrator 228 includes transistor pairs 234, 234' and 236, 236'. Each transistor pair is biased and coupled for alternate switching operation in the astable multivibrator mode. The two respective transistor pairs are themselves compound-connected in the Darlington configuration and operate in effect as a single electronic switching unit to provide for the necessary current amplification. The transistors 234 and 236 are each connected through a pair of load resistors 238 and 240 to the negative terminal of a DC source 242. A bank of cross-coupling capacitors 224a through 224d and 246a through 246d are connected to the multivibrator transistor switches through the selective setting of switches 245 and 247, respectively. It will be seen that the switches 245 and 247 function to cross-couple the collectors of the two transistors 234', 236', each to the opposing transistor pair base, to control the frequency of the machining power pulses provided to the machining gap. The switches 245 and 247 are normally connected for ganged operation. A pair of fixed resistors 248 and 250 and a potentiometer 252 are included in the multivibrator circuit, with the machining pulse on-off time controlled by the setting of the movable contact of the potentiometer 252. A pair of blocking diodes 254, 256 are further connected in circuit with the movable contact of the potentiometer 252. Also included in the multivibrator 226 are a pair of control input networks which control the off-time widening of

the multivibrator 226 through the transistor 234 or control the on-time reduction of the multivibrator 226 through the transistor 236. The first such input network includes the lead 257 and diodes 259 and 261 coupled as shown. The second such input network includes a lead 265 and a diode 267 which provide an input to control the on-time of the multivibrator transistor 236. A shielded connection of the two input leads is utilized. The pulse on-time is controlled in phase with the conduction of the transistors 236, 236'. The pulse off-time is controlled in phase with the conduction of the transistors 234, 234'. It will be noted that while the present invention and its several different embodiments utilize transistors as the electronic switches throughout the circuits, the invention is not so limited. Thus, with proper redesign of the circuit by those skilled in the art, any electronic switch in accordance with the definition previously supplied may be substituted.

The circuit of FIG. 6 will thus be seen to exemplify a circuit utilizing as a function control signal a signal derived from an LED. In the FIG. 6 circuit, a light-emitting diode is coupled in series with the machining gap and used with a pick-up phototransistor 221, which changes the light intensity signal into a proportionate electrical signal to control machining current being provided to the gap on an averaged pulse basis. Here again, the LED is used in the circuit to replace a standard sensing circuit which would include rather more complex networks, generally with electronic switches or diodes, which could be limited in their operation to an EDM circuit with one polarity of gap connection.

The circuit of FIG. 7 illustrates the use of a LED for a different function control with respect to an electrical discharge machining power supply. The showing of the circuit of FIG. 7 is substantially similar to the circuit of FIG. 6 but somewhat abbreviated. The circuit of FIG. 7 shows a light-emitting diode 220 which is connected with one of the principal electrodes or power conducting electrodes of the output transistor 212. The output transistors in any electrical discharge machining power supply are required to operate at very high frequencies and in some cases at relatively long on-times, which render their failure in a shortened condition possible. Should any of the output transistors 212 fail, there will be a surge of current to the electrode 12 and to the gap which may initiate a DC arcing or gap short circuit condition with damage to the gap elements and to other parts of the EDM power supply. For this reason, it is important to provide a sensing network with sufficiently rapid response time to sense the failure of the output transistor 212 and make a timely reduction in the power being furnished to the gap. In the FIG. 7 circuit, the LED 220 is operatively connected to the base of a phototransistor 221 in such manner as to control the output through its emitter and through a signal resistor 222 through an intermediate amplifier stage 223 and thence through the solenoid coil 225 which controls the opening and closing of a movable contact 227. The contact 227 is a normally closed contact to permit power to be connected to the gap between electrode 12 and workpiece 14, with the power being alternately connected and disconnected according to the controlled conduction of the output transistor 212. Upon failure of the transistor 212, a suitable actuating signal will be passed through solenoid coil 225 to pull the movable contact 227 open and thus interrupt the power to the gap to avoid damage to the elements. It

will be understood that other commonly known disconnect devices or circuits may be used to reduce the power to the gap in the event of a failure of an output transistor 202. The circuit of FIG. 7 illustrates a still further function control for an EDM apparatus in which a light-emitting device is particularly useful to provide an output signal readily convertible to a reliable electrical signal to protect the apparatus.

FIG. 8 illustrates an alternate embodiment for the light-emitting device in the form of a liquid crystal 300. A control signal such as from the machining gap is used to vary the light transmitting properties of the crystal 300. A continuous light source including bulb 302 and a DC source 304 is mounted at the right-hand side of the crystal 300.

It will thus be seen that by the present invention I have provided an improved sensing and protective system for detecting malfunctions within electrical discharge machining apparatus, which system is actuatable with a rapid response time to prevent any accompanying damage either to the power supply itself or particularly to the gap elements during machining.

What is claimed is:

1. In an electrical discharge machining apparatus for machining a conductive workpiece by an electrode tool across a dielectric coolant filled gap, a power source, a periodically operated electronic output switch operatively connected between said power source and the gap for providing machining power pulses thereto at frequencies ranging up to high frequencies, a pulse generator for controlling the on-time and the off-time of the machining power pulses, and a system for interrupting the operation of said switch responsive to gap short circuit condition, said system including a light-emitting device operatively connected to said gap for providing a light signal output which is a function of current passing through said gap, a light responsive means operatively connected to said device for providing a control electrical signal proportional to light signal magnitude, said light responsive means connected to the pulse generator for increasing the machining pulse off-time for the duration of said condition.

2. The combination as set forth in claim 1 wherein said output switch is operated by an independent type pulse generator and wherein said light responsive means is operatively connected to said pulse generator for controlling its operation and accordingly the on-time and off-time operation of said output switch responsive gap current representative of said condition.

3. The combination as set forth in claim 1 wherein said light-emitting device comprises a light-emitting diode, said diode operably connected in series with the gap for responding to gap current level.

4. The combination as set forth in claim 3 wherein said diode is connected in series combination with a resistor, said combination connected across a second resistor coupled in series with the gap.

5. The combination as set forth in claim 1 wherein said light-emitting device comprises an incandescent light bulb.

6. The combination as set forth in claim 1 wherein said light-emitting device comprises a constant light source and a liquid crystal mounted intermediate said light source and said light responsive means.

7. In an electrical discharge machining apparatus for machining a conductive workpiece by an electrode tool

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across a dielectric coolant filled gap, a power source, a periodically operated electronic output switch operatively connected between said power source and the gap for providing machining power pulses thereto, and a system for controlling the operation of said output switch responsive to gap short circuit condition, said system including a light-emitting device operatively connected to said gap for providing a light signal output which is a function of current passing through said gap, a light responsive means operatively connected to said device for providing a control electrical signal proportional to light signal magnitude, said electronic output switch operated by a pulse generator comprising a multivibrator including a pair of alternately operated electronic switches, one controlling the on-time and the other controlling the off-time of the machining power pulses, said light responsive means operatively connected to and controlling said pulse on-time controlling switch of said multivibrator for decreasing the on-time responsive to increased current flow through said device.

8. In an electrical discharge machining apparatus for machining a conductive workpiece by an electrical tool across a dielectric coolant filled gap, a power source, a periodically operated electronic output switch operatively connected between said power source and the gap for providing machining power pulses thereto, an independent type pulse generator for operating said output switch, said pulse generator comprising a multivibrator including a pair of alternately operated electronic switches, one controlling the on-time and the other controlling the off-time of the machining power pulses, and a system for controlling the operation of said output switch responsive to gap short circuit condition, said system including a light-emitting device operatively connected to said gap for providing a light signal output which is a function of current passing through the gap, a light responsive means operatively connected to said device for providing a control electrical signal proportional to light signal magnitude, said light responsive means being connected to said pulse off-time control switch of said multivibrator for increasing the machining pulse off-time responsive to increased current flow through said device representative of impending short circuit condition of the gap.

9. In an electrical discharge machining apparatus for machining a conductive workpiece by an electrode tool across a dielectric coolant filled gap, a power source, a periodically operated electronic output switch operatively connected between the power source and the gap for providing machining power pulses thereto, said output switch operated by an independent type pulse generator, said pulse generator comprising an astable multivibrator of precisely controllable on-time and off-time and a system for controlling the operation of said output switch responsive to gap short circuit condition,

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said system including a light-emitting device operatively connected to said gap for providing a light signal output which is a function of current passing through the gap, a light responsive means operatively connected to said device for providing a control electrical signal proportional to light signal magnitude, said light responsive means operatively connected to said multivibrator for increasing the off-time and at the same time decreasing the on-time of the machining power pulses furnished to the gap for the duration of the gap short circuit condition.

10. In an electrical discharge machining apparatus for machining a conductive workpiece by providing machining power pulses thereto from an electrode tool across a dielectric coolant-filled gap, a power source and a periodically operated electronic output switch operatively connected to said power source and to the gap for providing machining pulses thereto, a protection system for interrupting said machining pulses responsive to failure of said output switch in a shorted condition comprising a resistor coupled in series with one of the principal electrodes of said output switch, a light-emitting device connected in parallel with said resistor and operable to provide a light output signal proportional to current flow therethrough of a magnitude sufficient to indicate output transistor failure, and a light responsive means linked to said device for providing an interruption of said machining pulses during said failure.

11. The combination as set forth in claim 10 wherein said light responsive means comprises a phototransistor having its base operatively connected to said light-emitting device for providing an electrical control signal proportional to said light signal, wherein said phototransistor has its output operatively connected to said power source to provide disconnect of said source responsive to said condition.

12. The combination as set forth in claim 10 wherein said light-emitting device comprises a light-emitting diode phased to permit normal power flow to the gap.

13. The combination as set forth in claim 10 wherein said light-emitting device comprises an incandescent type light bulb.

14. The combination as set forth in claim 10 wherein said light-emitting device comprises a constant light source and a liquid crystal mounted between said light source and said light responsive means.

15. The combination as set forth in claim 11 wherein said power source has a relay operatively connected to it and controlling its connection to said gap, said electrical control signal operable to actuate said relay and to interrupt said power source connection during failure of said output transistor.

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**UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION**

Patent No. 3,825,713 Dated July 23, 1974

Inventor(s) Oliver A. Bell, Jr.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 3, line 43, delete "are" and substitute --art-- therefor;

Col. 8, line 40, delete "228" and substitute --226-- therefor;

Col. 9, line 23, "delete "hich" and substitute --which-- there-
for.

Claim 7, line 11, delete "light" and substitute --put-- there-
for.

Signed and sealed this 19th day of November 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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